Floods - causes, future risks and mitigation strategies

The floods of the 2013/2014 winter provided an excellent opportunity for politicians and commentators to demonstrate their knowledge of hydrology. Owen Paterson suggested that SuDS would help the Somerset Levels, David Silvester (UKIP) weighed in with the link between floods and gay marriage and Eric Pickles queried the expertise of the Environment Agency (although he at least managed to avoid suggesting that floods were linked to a lack of weekly bin collections). Given that much of the commentary has been a bit confused, it seems an opportune moment to review some of the basic science of flooding and how it relates to the built environment. Judith Thornton reports...

The first thing we need to do is to consider the types and sources of flooding. Obviously our potential to prevent and mitigate floods differs considerably according to the source of the water; the basic types of flooding are as follows:

Fluvial: this occurs when the flow in a river exceeds what can be contained within the banks, which is then overtopped and the water inundates surrounding land. These flood events are generally associated with prolonged rainfall over the course of days/weeks, and so are more common in winter. More rarely, localised intense rainfall, particularly in 'flashy' catchments (characterised by steep slopes and rapid surface run off) can also cause sudden fluvial flood events (eg. Boscastle in 2004). Levees, or other river bank defences designed to prevent fluvial flooding occurring, will also prevent the water draining back into the watercourse as the water levels go down.

Pluvial: (also known as surface water or flash flooding): this type of flood event is characterised by high intensity rainfall, often over a relatively small area, which exceeds the capacity of the drainage system. Pluvial flood events are generally fairly short lived (hours rather than days) and highly localised. These are most prevalent in urban areas due to the presence of smooth impermeable surfaces, and can occur year round. Summer thunderstorms can have peak intensities exceeding 10cm/hour, sufficient to overwhelm almost any drainage network, and in some major UK river basins (eg. the Thames), long term hydrological monitoring[1] indicates that maximum daily rainfalls occur in summer. Surcharging of sewers is often included in this category – sewers designed to take relatively small and constant flows of sewage are rapidly overwhelmed by surface water drains connected into the sewer system; a rain event can rapidly increase the volume of liquid requiring conveyance to 20 times the design flow.

Groundwater: this type of flooding tends to occur after a prolonged period of rainfall (over weeks/months) and is when the water table reaches the ground surface (so is often first noticed in basements). It is generally slow in onset and it is often difficult to predict the likely magnitude of the event. Groundwater movement and mapping is a particularly difficult science.

Coastal: these are generally caused by a combination of low atmospheric pressure, high tide and strong winds. They can be particularly destructive given the force of the water and the stones/sand/silt within it. However, they are relatively easy to predict, allowing preparations to be made.

Breaching of infrastructure: reservoir failure is the most dramatic example of this type of flooding, and thankfully the rarest. The release of large water volumes causes immediate catastrophic damage, sweeping away everything in its path.

Flooding caused by debris: minor obstructions to flow (such as fences across rivers to prevent stock escaping, and bridge stanchions) can accumulate debris such as tree branches and cause major obstructions to flow and therefore overtopping of stream/river banks upstream. Whilst this isn't technically a separate category of flooding, it is worth emphasising since it results in flood events in unexpected locations, and also has the potential to seriously exacerbate the severity of flooding that is already occurring. In urban areas, even relatively small amounts of leaves or litter on the street can cause surface water drains to become completely blocked and pluvial flooding to occur, again in unexpected locations.

Floods in combination

These categories of flooding are a simplified picture, and as we have seen this winter, these phenomena can combine to produce more extreme flood events[2]:

- prolonged rainfall caused not only fluvial flooding, but led to groundwater levels being unusually high and therefore prolonged flood events in many areas beyond what would be normal for fluvial flooding (South East of England).
- Severe coastal flooding occurred (eg. Aberystwyth, Dawlish) when low atmospheric pressure and strong winds (which increase wave height) combined with a spring tide.
- Tide locking (the period of time when water in a tidal river cannot flow out to sea because of the relative levels of sea and river) exacerbates fluvial flood events. Whilst not a cause of the flooding in the Somerset Levels, high tide levels reduced the volumes of water draining from the Levels.
- Sudden increases in winter temperatures that cause rain to fall on frozen ground can result in flooding due to the combined effect of low infiltration rate into the ground and snow melt, providing extra volume for the flood event (eg. the 1947 Thames flood, which was the worst of the 20th century).

From mechanism to mitigation

Once we understand the type of flooding, we can consider the best strategy for preventing a flood event, and/or mitigating the impact that it has. Whilst relatively simple (albeit expensive) solutions exist for some types of flooding and can be widely applied, in many instances, the wider catchment needs considering in order to avoid a solution at one location creating problems in another. Consequently, the following discussion focuses on broad categories and emphasises links between systems.

Land management and its impact on flooding

Around 76% of land area in the UK is agricultural, and of this, 65% is grassland. The link between rainfall on grassland and surface water generation is relatively well understood. The predominant influence is whether or not drainage systems have been installed (generally consisting of dug channels in upland areas, and field drains in lower lying areas). Limiting the rate of runoff via these drainage systems is the key to solving the problem, and for upland peat, this has the added benefit of preserving our largest terrestrial carbon store. Where blocking drainage systems isn't appropriate, appropriately sized ponds can attenuate runoff locally to maintain a balance between agricultural needs and the flood risk of downstream communities. On arable land, the problem is less about drains, and more about soil management. Furrows for planting and tramlines from vehicles can rapidly become water channels, and from a theoretical perspective, relatively simple changes in farming practice can mitigate this. Clearly the nutrient and soil loss from agricultural land that accompanies the surface water runoff also represents both an environmental problem and a loss to the farmer. However, fields are often undulating rather than having a single slope direction, access tracks are designed to maximise the productive area of land and to minimise the length of vehicle travel and soil compaction, and it is dangerous to operate machinery on side-slopes. Given that fluvial flooding is predominantly a winter problem, in practice the biggest single measure that could improve land management in arable areas is to minimise the amount of bare ground over winter, but this will impact on crop choice, growing period and management regime. As summarised by a recent German paper[3] on the variables affecting surface water runoff from arable fields, “agricultural operations introduce a man-made seasonality to soil hydraulic properties”.

Woodland, in the right places and if appropriately managed, can decrease the amount of water that runs off the ground surface, in addition to benefits such as biodiversity, CO_2 sequestration, timber production, amenity and potential to produce biofuel. However, forestry in general and afforestation in particular has rather mixed impacts in terms of its effects on the water environment, and is highly dependent on where it is located, species mix, land area covered, and management approach[4]. Soil erosion is worse in forested areas than on pasture (and this is particularly true of UK upland forestry). Access tracks installed to facilitate woodland management must be drained by culverts, and these increase water runoff from areas during extreme events, so the woodland exacerbates flooding rather than reducing it. Planting trees is certainly not a flood management panacea unless extremely carefully managed. At a smaller scale, trees planted as shelterbelts for livestock on grassland are moderately effective at reducing surface water generation when planted perpendicular to the slope and fenced to keep animals off[5].

However, even under ‘ideal’ land management conditions, the extent to which water will infiltrate to ground during winter is limited by physical factors, including soil type and depth, and the hydraulic gradient (which relates to the soil moisture deficit and groundwater level). Consequently, our approach to managing agricultural land needs to include catchment level decision making on the consequences of land use on local flood risk, soil carbon and water quality. In catchments with large populations downstream, blocking drainage channels, removing field drains, and changing arable mix to decrease the amount of bare ground over winter may be appropriate in order to achieve an acceptable degree of flood risk lower in the catchment, but raises an enormous number of practical problems. The Thames drainage basin is 5000 square miles, and the Environment Agency estimate that 135,000 properties are at risk of fluvial flooding (at a 1% or greater annual probability), and a further 300,000 from tidal flooding. In many catchments, there are difficult choices to be made regarding what an acceptable level of risk is. Further information at a catchment-specific level is given in Catchment Flood Management Plans (CFMP)[6].

Preventing pluvial flooding in urban areas

As stated earlier, pluvial floods are relatively short lived. They are exacerbated by the existence of combined sewers that carry both storm water and sewage. This is a historical legacy. Whilst we moved away from connecting surface water drains to the foul sewer network in the 1950's, and several billion pounds has been spent on removing combined sewer overflows since privatisation, it is not realistic to replace all the UK's combined sewers. New building developments are required to limit the rate of surface water runoff, in order that they do not exacerbate pluvial flooding issues, and to have separate surface and foul water sewers (although in many instances this separation ceases at the boundary of the development when the connection is made to existing infrastructure). In practice the potential to infiltrate water to ground is very limited in most developments, and so a more common strategy is to provide attenuation. The volume of attenuation required determines what type of system is necessary and therefore the vital first step is to calculate this volume, before deciding on an approach (this is location dependent, but is unlikely to be less than 500m^3 per hectare). In essence there is a choice between simple tank type structures and a variety of softer solutions, such as detention basins, ponds, green roofs and swales, which can provide part of a wider green infrastructure approach. Tank based systems have a much lower land take per m^3 attenuation (as they can be installed below access roads, car parks etc), but the latter have wider environmental and amenity benefits. When the price of land is factored in, convincing developers to allow space for green infrastructure is difficult, and problems with long term adoption and maintenance agreements, and a lack of quantitative modelling by proponents of green infrastructure systems, have limited their uptake by mainstream developers.

Lowlands and flood plains, coastal interactions

The majority of lowlands and flood plains in England and Wales have been subject to significant engineering modifications to drain them and make them more suited

The impacts of coastal flooding on the railway near Tywyn, Gwynedd. The railway embankment forms part of the coastal flood defence here, as is the case on many coastal railways.

to agriculture; both the Fens and the Somerset Levels have been artificially drained for several hundred years. From around the 1930's to the 1970's a vigorous policy of land drainage was pursued, led by the Ministry of Agriculture with the aim of safeguarding food production. Flood plains are a vital part of the aquatic ecosystem, and so from an environmental perspective, should be allowed to flood. The frequency at which they do so, can, to a limited extent be controlled by dredging, but because the volume of water that can be stored on a flood plain is orders of magnitude greater than that which can be contained in a river, dredging would not have prevented this winter's flooding of the Somerset Levels. Indeed, dredging can make flooding worse downstream, and particularly in areas where there is a tidal influence[7].

Whilst we'll all be familiar with Armageddon-style maps showing what the British coastline would look like with 100m sea level rise, the reality is obviously much less dramatic[8]. It's reasonable to expect that coastal flood defences will be maintained in areas with high population density; the Thames flood barrier is expected to provide sufficient protection until 2060[9], and a long term study of flow in the Thames has demonstrated its resilience to flood events (and that this is partly attributable to river management)[10]. A much better source of information on the future shape of the UK coastline is shoreline management plans (SMP). These documents, compiled in consultation with local stakeholders, are in effect both a risk assessment and a policy document setting out high level guidance on the way in which the coast could be managed for the next 100 years[11]. These, in turn, feed into UK government policy on flood and coastal defence. In some areas the policy recommendation is to 'hold the line', but 'managed realignment' is also stated policy for numerous locations, with decisions being based on the number of communities affected, their future viability (eg. in relation to transport links which may also be inundated), and the environmental consequences. In most instances, Shoreline Management Plans (SMP's) fail to help with difficult decisions in the short term. The lack of mechanisms and precedents for relocating communities when managed realignment is the long term solution is a serious problem. This is less about cliffs eroding and houses falling into the sea, and more about low lying coastal areas, such as the Somerset Levels and the Fens. The Fens are particularly significant in terms of their agricultural productivity, the number of communities involved and the area of land affected.

What does this mean for building designers?

Many of the mitigation measures discussed above are well beyond the remit of building designers. However, the most important action we can all take is to minimise the climate change impacts of the building. In terms of practical water-related measures on the ground, the most obvious advice is not to build on flood plains, and if there are watercourses on site, to take this into account when laying out the site in order to minimise the risks of fluvial flooding. In terms of pluvial flooding, calculate the surface water runoff of your site pre-development, and endeavour to ensure that post-development runoff is the same or lower (development on brownfield sites provides particular opportunities for actually ameliorating flood risk rather than simply not making it worse)[12]. In most instances, this will involve some form of attenuation, and if space permits and the calculations demonstrate that the attenuation provided by SuDS would be sufficient, it might be preferred, given its wider benefits.

In areas where flooding remains a risk, there are a number of measures that can be used to minimise the likelihood of floodwater entering the building. Consider removable flood boards for doors and low level windows, as these are far more effective than sandbags. Know where your airbricks are and get covers for them. Any drain out of the building can also be a source of water leaking in, so this will include washing machine and dishwasher drain outlets as well as toilets and baths/showers/washbasins. Plug where possible, and weigh down with a sandbag. Special inflatable bladders are available to inflate in the U bend of toilets. If you have sewer manholes on your property, it is worth weighting them down with sandbags if flooding is imminent. This reduces the risk of the cover floating off and is all you can do to minimise the sewage contamination that is associated with flooding. In a new build situation, where flood risk is considered high, choice of materials and finishes can have a major impact on the expense and extent of repairs necessary after flooding. Guidance on this is available[13], but it should be remembered that this is very much treating the symptom rather than the cause, and you should question the logic of building in that particular location.

Summary

So, were the 2013/14 floods attributable to climate change? This is a tricky question (and one I have deliberately avoided). Weather in the UK has always had extremes, and collecting sufficient data to detect long term changes in the peak and frequency of these extremes, and then finding sufficient evidence to attribute them to a cause is difficult[14]. Two things are, however, pretty clear; extreme rainfall events are a predicted consequence of a warmer planet (based on the laws of physics), and secondly, in terms of flood risk over the next 50 or so years in the UK, sea level rise is much less of a concern than the frequency of extreme events. Given that the causes (and therefore solutions) to flooding have wide ranging consequences and must also fit in with other issues relating to ecosystems services, policy decision making tools and approaches are needed that allow a diverse range of factors to be incorporated, and joined up decision making platforms are needed[15]. As noted by some commentators this winter, long term policy should not be decided during times of crisis, and to finish on a positive note, the evidence base we have now on which we can base UK policy is immeasurably better than it was ten years ago.

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Refs.

1. Huge amounts of hydrological monitoring data are available in the UK. A good starting point is the National River Flows Archive: www.ceh.ac.uk/data/nrfa/index.html, in particular the monthly and annual hydrological reports, and the occasional reports on extreme events.

2. A description of historical UK flood events is given by Robson (2002). Evidence of trends in UK flooding. Philosophical Transactions of the Royal Society of London 360: 1327-1343.

3. Fiener et al. Surface runoff from arable fields in central Europe. Hydrology and Earth System Sciences. 17. 4121-4132.

4. At the other extreme, forestry contributes to decreases in groundwater recharge and the closure of river basins (eg. in India), because afforestation has occurred in areas where evaporation exceeds rainfall. In the UK, a study of the impacts of increasing woodland cover in lowland areas demonstrated the negative consequences of this for water availability and for nitrate levels in groundwater. A good summary of the role of forests in water management is given by Calder (2007). Forests and water – ensuring forest benefits outweigh water costs. Forest Ecology and Management 251: 110-120.

5. The most studied example of this is Pontbren; an area of the Cambrian mountains, forming the headwaters of the Severn. Described in McIntyre et al. (2012). The potential for reducing flood risk through changes to rural land management: outcomes from the Flood Risk Management Research Consortium.

6. Available from the Environment Agency website: www.environment-agency.gov.uk/research/planning/33586.aspx

7. An excellent overview of the role that dredging can (and cannot) play is available from CIWEM: Floods and Dredging – a reality check. February 2014: www.ciwem.org

8. These maps are rarely based on data; the IPCC predicts a 62cm sea level rise by 2100. They rarely include a correction for tidal range, or coastal flood defences.

9. And the EA produced a map showing the likely impact of the 5th December tidal surge in the absence of the Thames Barrier. Dramatic illustrative scenarios also exist for Hull and Portsmouth in 'Facing up to rising sea levels' produced by Building Futures: www.buildingfutures.org.uk/projects/building-futures/facing-up/facing-up-to-rising-sea-levels-pdf/

10. Marsh & Harvey (2012). The Thames Flood series: a lack of trend in flood magnitude and a decline in maximum levels. Hydrology Research 43. 203-214.

11. The most accessible way of reading shoreline management plans is to use the Environment Agency coastal erosion online map: www.environment-agency.gov.uk/homeandleisure/134831.aspx

12. A simple first pass analysis for flood risk is to put the postcode of the site into the Environment Agency flood risk website; this separates pluvial, fluvial/coastal and reservoir flooding. Calculations regarding the volumes of flood attenuation required can be undertaken using the tools available from: www.uksuds.com

13. www.planningportal.gov.uk/uploads/br/flood _ performance.pdf has plenty of illustrations and is a good starting point.

14. 'The Recent Storms and Floods in the UK', a joint report from the Met Office and Centre for Ecology & Hydrology considers this in some detail: www.metoffice.gov.uk/media/pdf/n/i/Recent _ Storms _ Briefing _ Final _ 07023.pdf.

15. An example is Polyscape, which looks at synergies and trade-offs for various ecosystem services under different land management scenarios. Jackson et al (2013). Polyscape: A GIS mapping frameworks providing efficient and spatially explicit landscape-scale valuation of multiple ecosystem services. Landscape and Urban Planning 112. 74-88.

Dr Judith Thornton has been obsessed with water for many years, and given that there is so much of the stuff about, albeit mostly in the wrong place at the wrong time, she expects to remain obsessed with it for the foreseeable future. She works at the Institute of Biological, Environmental and Rural Sciences at Aberystwyth University. Previously she was at the University of Leeds working on water footprints, and has also worked at the Welsh School of Architecture, Cardiff, and at the Centre for Alternative Technology as a lecturer on their MSc courses.
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